Basin-scale particle flux responses to episodic events

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Introduction. Lake Michigan is a virtually enclosed basin with a hydraulic residence time of approximately 100 years. Extensive sediment-water coupling during the six month unstratified period has been reported and is required to close large mass-balance inequities for nutrients and contaminants. Recent period. Events in southern Lake Michigan in 1996-98 resuspended more fine-grain sediments (>1MMT) than the estimated total annual external load. Based on water intake turbidity records, the 1998 event was the most intense in 37 years. During the main resuspension event in March, 1998 mass fluxes (<62um particles) in near-coastal traps increased from 16 to 876 g/m2/d and the flux of total phosphorus from 12 to 380 mgP/m2/d. The intensity, duration, and timing (relative to stratification and the beginning of the spring plankton bloom) of these episodic events are being investigated to estimate their impact on lake ecosystems on annual time scales.

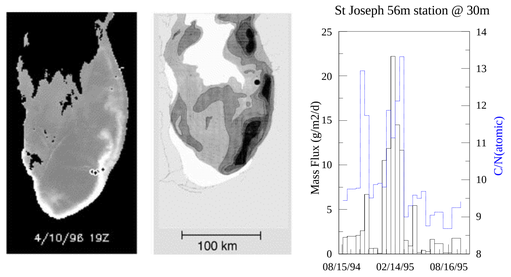

Figure 1. (a). AVHRR channel 1 (visible) imagery of the plume on April 10, 1996; clouds are masked out in black. The plume was initiated by a major storm on March 20 and appears to be an annually recurrent event. The offshore advection of major features on the eastern side of the lake coincide with the regions of maximum sediment accumulation. The plus symbols are locations of water sampling on this day (Eadie et al., 1996). (b). Thickness of post-glacial sediments; zero accumulation in the white region (non-depositional) and less than 1 meter in the lightest shade of gray (transitional). Subsequent contours are in 4 m thick intervals, with the black regions having greater than 14 m of total accumulation. (c). Mass fluxes recorded in a sequencing trap in the plume and high sediment accumulation region (near the easternmost + symbol in a). Fluxes are in 15 day intervals covering the period 8/94-8/95. The critical feature illustrated is that approximately 90% of the mass of particulate material delivered to this site arrived in less than 10 weeks during the winter-spring period.

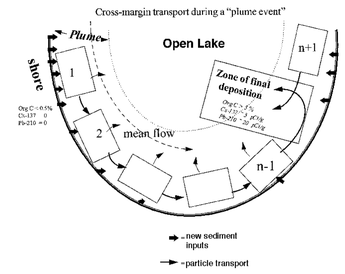

Figure 2. A simple conceptual model of the movement of particles in the coastal plume in the southern basin of Lake Michigan. Particles derived from the western shore move counter-clockwise in concert with the mean circulation. Major questions include how quickly these particles move from source to sink, the number of deposition/resuspension cycles that they undergo in transit, the transformations that occur in route, and offshore transport. An important parameter therefore is the residence time for particles within the plume, a function of both the inventory in each compartment and the flux "down stream." Radionuclides may be used to "clock" the speed with which particles move and yield the "apparent age" of particles within the system.

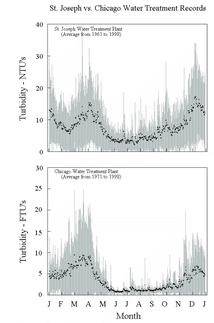

Figure 3. Long-term records of turbidity from the St Joseph and Chicago Water Treatment Plants provide a historical perspective of the timing and duration of the events. Black circles represent the average daily turbidity and the gray envelope a one standard deviation spread.

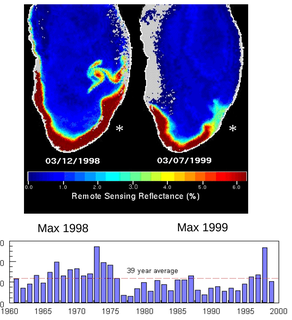

Figure 4. Satellite images of the plume maxima for 1998 and 1999. The lower panel is a bar graph of the annual maximum 10 day running mean for 39 years of turbidity from the St Joseph Water Treatment Plant (located near the *) The 1998 event was the largest recorded over that period while the 1996 (Figure 1) and 1999 were somewhat below the long-term average.

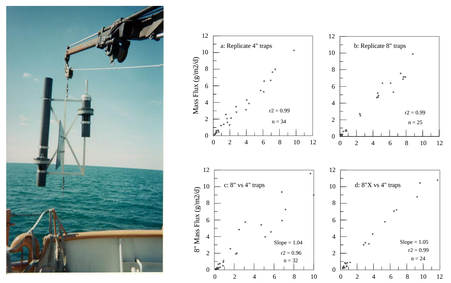

Figure 5. A standard GLERL autosequencing sediment trap (left), paired with a test version. The standard trap has an 8" ID and an aspect ratio of 8:1 above a funnel leading to a 60ml, poisoned, collection bottle. The bottles are located in the circular carousel. Sampling intervals are pre-programmed for each collection bottle. The adjacent four figures provide information on trap precision from paired traps as illustrated in the picture. The collection efficiency of this design has been examined by several investigators and found to be the best for the conditions common to the Great Lakes.

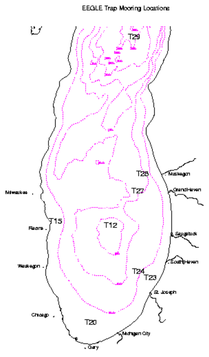

Figure 6. Locations of the main trap moorings for the EEGLE program. The nearshore stations (15, 20, and 23) are located in 25m and are positioned to provide information on resuspended source materials. There have been troubles here, fouling by zebra mussels, and flux rates too large for the trap designs. Station 24 is (hopefully) located near the core of the plume, while station 12 is located to provide information on lake-wide response to the event. Stations 27 and 28 are long-term monitoring locations and provide temporal context (see figure 9).

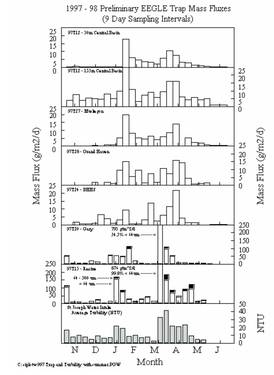

Figure 7. Mass flux results for the 1997-98 field year, the largest recorded event in 39 years. Each panel represents a single trap, the bottom panel is the average turbidity data at St Joseph for the same intervals. We screened each trap sample at 63um and found small amounts of materials larger than that (black portions of the bars) in the near-shore traps during the event. However, the majority of the resuspended materials was a major event in January for which we don't have satellite imagery. Rapid decay of the fluxes after the event provides a scale time of days-weeks for the majority of transport.

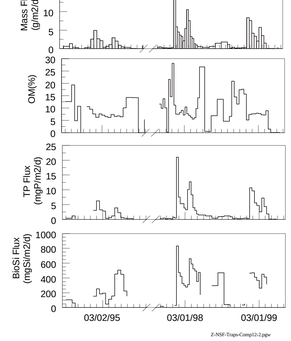

Figure 8. Three years of trap data from the center of the southern basin (station 12) at 30m below the surface. We have estimated the quantity of resuspended material as 1 and 4 million metric tons for 1995 and 1997 respectively. The first was somewhat below the 39 year average recorded at St Joseph (figure 3) while the latter was the largest signal. One million MT is approximately the total annual input of fine-grain materials from all external sources.. We are using organic carbon, biogenic silica and carbon isotopes to provide insight into the basin-wide productivity response from these resuspension events. Inconclusive at this time.

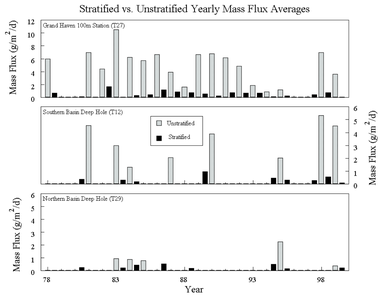

Figure 9. A summary of long-term mass fluxes for the 6 month stratified (black) and unstratified (gray) periods in Lake Michigan. Over the course of 20 years the fluxes to near-surface traps at these sites (>100m total depth) have ranged over a factor of 10 and there is a distinct lack of correspondence between the north and south basins. Trap flux data are being used to constrain whole-lake sediment resuspension and transport models. Tracers will hopefully provide information on sources and productivity responses to the events, and samples are being analyzed for nutrient and contaminant fluxes.

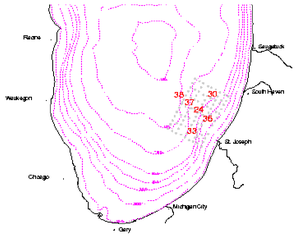

Figure 10. Trap (numbered stations) and sediment box coring locations (symbols) within the region of maximum sediment accumulation in Lake Michigan (see figure 1). This experiment is designed to measure the rates of delivery of mass and short-lived radionuclides to this site and determine the time scales for sediment transport into depositional regions. Further details of this experiment can be found in the posters of Robbins, et al. and Klump, et al.

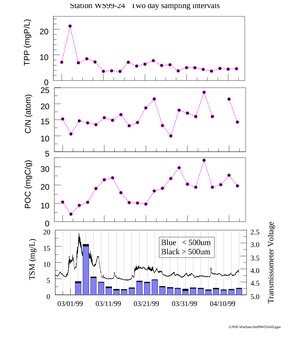

Figure 11. A remotely deployable automated water sampler has been successfully constructed and deployed at trap station 24. The sampler pumps raw water into 24, independently programmable 1L bottles. In this test sequence, the March, 1999 plume event was captured and suspended matter, carbon and phosphorus were measured. A 25 cm transmissometer was co-located with the sampler intake at 30m below the surface in 56m total water depth. Some details of the plume are well represented in this suite of samples, including the rapid relaxation time of the local turbidity. Next year we hope to have a total of four of these samplers.

Summary. Preliminary results imply that the mass of reflective substances in the plume is approximately equal to the total annual particle load to the lake. The compositional results presented here are consistent with a conceptual model where silty-clay materials eroding from bluffs along the shore of Lake Michigan or from exposed glacio-lacustrine clays in relatively shallow waters form temporary deposits of particles in patchy, transient reservoirs at the sediment-water boundary. These reservoirs serve a very important function in mediating the movement and characteristics of particles, nutrients and contaminants between their source and their ultimate sink. Local mixing processes blend these materials with the inventory of resuspendible sediments within the lake. Large episodic events like the plume event, massively resuspend and transport these materials and re-expose them to the pelagic system where they are further altered. Finally, the offshore eddies in the southeastern portion of the plume coincide with the area of maximum sediment accumulation in the lake, implying that this event also plays an important role in shaping observed depositional patterns and in mediating subsequent sediment-water interactions.

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